INHERITANCE OF QUANTITY AND QUALITY OF MILK PRODUCTION IN DAIRY CATTLE

By W. E. Castle

Bussey Institution for Research in Applied Biology, Forest Hills, Mass.

Communicated, August 1, 1919

In 1911 the late T. J. Bowlker undertook at his farm in Framingham, Mass., an experimental study of inheritance in dairy cattle by the modern method of crossing pure breeds and looking for a recombination in the second crossbred generation of the characters differentiating the breeds crossed. The breeds which he selected for study were the Holstein-Friesian and the Guernsey, one supreme among dairy breeds in quantity production, the other of very high rank as regards quality of milk produced. It was his belief that if quantity and quality of milk production were independently inherited characters, it should be possible to combine them in a single race by the method of crossbreeding, in accordance with Mendel's law. The desired recombination of qualities, if attainable, would be of much importance to the dairy industry, and at any rate the knowledge whether such recombination is attainable would be a valuable contribution to science. With rare insight into the difficulties surrounding the problem and the proper method of attacking it, Mr. Bowlker planned his experiment on a considerable scale. He had a herd of some 40 pure-bred registered cows, about two-thirds of them being Holsteins, the rest being Guernseys. He also had a pure-bred registered bull of each breed, and in the pedigrees of these bulls excellent blood-lines were represented. He decided to cross-breed the entire herd, mating the Holstein cows to the Guernsey bull and the Guernsey cows to the Holstein bull. In this way what are known as reciprocal crosses were made between the two breeds. In all about 140 F_1 calves were produced between the years 1912 and 1919. As fast as the F_1 heifers attained suitable age they were bred to F_1 bulls in order to secure the desired F_2 generation, in which combination of characters might be expected. About 35 living F_2 calves have been produced in this way of which the heifers have been saved for milking tests, for which, however, they are still too young.

Mr. Bowlker did not live to see the completion of his experiment but died in February, 1917. His family undertook to complete the unfinished work, with such scientific advice as I could give them, but practical difficulties having arisen which make it impossible to carry the work

further on the Bowlker farm, arrangements have been made for turning the entire project over to the University of Illinois, where experts in dairying and genetics will study the results in hand and such as may be forthcoming. At the generous suggestion of the new owners of the herd I am making this preliminary statement of results obtained at the Bowlker farm.

Throughout the experiment the herd has been under the same system of management and in charge of the same superintendent, Mr. Leon Haley. The care and feeding have been such as are given to ordinary farm herds and the cows have been milked twice a day. Pure breds and crossbreds have been kept in the same barn and treated alike in every respect. The milk from each cow has been weighed at each milking and these records are now available for study. Occasional butter-fat tests have been made for each cow but these are fewer than could be wished and make it possible only approximately to estimate the total butter fat production of each cow.

Both the F_1 and the F_2 cross-bred calves have proved vigorous and have grown well. Some data have been accumulated on the relative growth-rates of the pure-bred and the cross-bred calves but these are insufficient as yet to lead to any definite conclusions. It should be observed, however, that the F_1 cows have calved for the first time at a slightly earlier age than the cows of either pure breed kept on the farm, a bit of indirect evidence that in vigor and early maturity they conform to the usually high standard of cross-breds. The recorded observations on weight of milk given by pure bred and by F_1 cows and the estimated amounts of butter-fat contained in this milk are summarized in tables 1, 2 and 3. Only data for comparable ages and lactation periods (first and second) are included in the tables. The column 'age' shows the approximate age of the cow at the beginning of the lactation period. The column 'time' shows the duration in months of the lactation period. If no entry is made in this column it will be understood that the lactation period covered a full year. The column 'total pounds milk' shows the amount of milk produced during the twelve months or less of the lactation period. No account is made in this summary of milk produced after the cow had been in lactation for more than twelve months.

Table 2 shows that 25 pure-bred registered Holsteins calving at an average age of 2.8 years gave in their first lactation period an average of 7673 pounds of milk. The amount of butter-fat in the milk can be stated for only 8 of the 25 cows those which were still in the herd when the systematic taking of butter-fat tests for individual cows was undertaken. For these 8 cows the estimated butter-fat percentage is 3.4.

Since this agrees closely with Roberts'[1] finding for the breed in general, it will be assumed to hold for the entire group of 25 cows. On this basis the average butter-fat production for the Holstein cows in their first lactation period would be 261 pounds.

TABLE 1

MILK AND BUTTER-FAT PRODUCTION OF F_1 COWS

COW	FIRST LACTATION PERIOD					SECOND LACTATION PERIOD			
	Age	Time	Total pounds of milk	Fat	Total fat	Age	Time	Total pounds of milk	Total fat
		months		*per cent*			*months*		
*Alice	2 1/3		8,070	4.0	323				
Annie	2 3/4	9	(5,460)	4.3	235	3 1/2		7,536	324
Bessie	3 1/3	10	(6,297)	4.0	252				
Blackfoot	2 1/4		7,755	4.1	318	4 1/6		10,125	415
*Daisy	3 1/3	11	(7,661)	4.3	329	4 1/6		9,375	403
Dora	2 3/4		7,908	4.2	332	4		11,538	484
Ellen	3 1/6	9	(6,096)	4.2	256	4 1/6	11 1/2	(8,949)	376
Emerald	2 1/2		8,517	4.1	349				
Emma	2 3/4	7	(3,768)	4.0	151	3 2/3	9 1/2	(7,080)	283
Fairiel	2 1/4		4,740	4.6	218				
Fanny	2 5/6	9	(5,325)	4.0	213	3 3/4		9,135	365
*Freckles	2 1/6		7,773	4.0	311	3 1/3		8,340	333
*Grace	3	11	(5,796)	4.3	249				
Inka	2 1/3		7,881	4.3	338				
Jane	2 1/4		7,809	4.5	351	4 1/3	11	(8,646)	389
Julia	2 5/8	10 1/2	(6,498)	4.6	279	4		8,835	406
*Kate	2 3/4		7,689	4.5	346				
Lavaine	2 1/2		5,550	3.7	205				
*Lilvene	3 1/6	11	(6,000)	4.1	246				
Lilac	2 1/6	11	(7,542)	3.8	286	3 1/6		6,489	246
*Mary	2 3/4		(8,199)	4.0	327	4 1/2	11	(8,871)	355
Nancy	2 1/2		4,899	4.3	210				
Peach	2 1/3		8,508	3.8	323				
Pearl	2 1/2		7,446	3.7	275				
Peggy	2 1/2		6,507	3.8	247				
*Ruby	2 1/2	9	(4,440)	3.7	164				
Sapphire	3 1/6		6,618	4.0	264				
Susan	2 1/6	10 1/2	(6,168)	4.1	252				
Sylvene	2 1/6		6,075	4.0	243				
Tessa	2 1/2	11 1/2	(5,700)	4.4	250	3 1/2		7,710	339
Twisk	2 1/2		6,252	3.8	237				
Average	2.61	11.14	6,612	4.08	270	3.88		8,663	363

In table 3 are summarized the milk production records of 8 pure-bred registered Guernsey cows which also formed a part of the Bowlker herd. They calved for the first time at an average age of 2.7 years and gave in a first lactation period of from seven and one-half to twelve months

an average of 4617 pounds of milk. The recorded butter-fat tests of these cows are too few to form an adequate basis for estimates of their individual butter-fat production. But such tests as were made agree sufficiently well with Roberts' estimate of 5.0% for the breed. On this

TABLE 2

MILK AND BUTTER-FAT PRODUCTION OF PURE-BRED REGISTERED HOLSTEIN COWS

COW	FIRST LACTATION PERIOD					SECOND LACTATION PERIOD			
	Age	Time	Total pounds of milk	Fat	Total fat	Age	Time	Total pounds of milk	Total fat
		months		*per cent*			*months*		
H. S. Clotilde	2½		7,765	3.5	271	3⅚	10½	(9,803)	343
H. S. Inka	3		9,089	3.4	309	4¼	8	(8,866)	301
H. Perfecta Clotilde	3¼	9½	(8,030)	3.2	257	4¼	11	(10,025)	320
H. S. Judy Colantha	3¼		8,875	3.6	319	4½	11	(9,455)	340
H. S. Katharine	2¾		8,247	3.2	264	4½	10	(9,263)	296
H. S. Pietertje	2½	9½	(6,887)	3.2	220	3½	9	(8,631)	276
H. S. Twisk	2½	9	(7,701)	3.4	261	3½		10,312	350
H. S. Wachusett	2½	10	(6,481)	3.6	233	3½		10,813	392
H. M. Cre. DeKol	2¾	8½	(5,432)		Av. 267	3⅔	11	(7,619)	Av. 327
H. S. Erie Colantha	2½		6,417			3½		10,470	
H. S. Erie Vernon						3⅔		10,248	
H. S. V. Julipana	3⅓		8,582						
H. S. Landor	2 11/12		7,725						
H. M. Segis	2⅚	9½	(8,900)			3¾		10,327	
H. S. Vale Judy	3		10,101						
H. S. Veldoor	3¼	10½	(7,445)			4⅙	10	(9,555)	
H. Cre. Mercedes DeKol	3⅙	8½	(8,928)			4⅓	9	(8,186)	
H. M. Judy Colantha	2⅔		5,493			4⅙	7½	(6,170)	
H. L. Whetstone DeKol	2 11/12	9½	(5,230)						
H. A. Cre. DeKol	3		7,479			4⅓	11½	(8,961)	
H. I. Colantha DeKol	2½		7,692			3¾	9½	(7,490)	
H. Tessa Netherland	2⅚		9,699			4½	10½	(9,190)	
H. C. Plum	2⅚		8,628			4¼		11,989	
H. S. Dexter Erie	2½		7,945						
H. Judy Cre. DeKol	3	9½	(7,399)			4	11½	(12,041)	
Average	2.825	11.0	7,673	3.4	261	4.0		9,475	322

basis the average butter-fat production of the 8 Guernseys in their first lactation period would be 231 pounds.

Table 1 shows the observed milk and estimated butter-fat production of 31 F_1 cows which calved at the average age of 2.6 years, one-tenth of a year younger than the Guernseys, two-tenths of a year younger than the Holsteins. They produced an average of 6612 pounds of milk.

This is 1061 pounds less than the average yield of the pure Holsteins, but is 1995 pounds more than the average yield of the pure Guernseys. In other words, the average yield of an F_1 cow exceeds the half-way point between Holsteins and Guernseys by 467 pounds.

As regards butter-fat content of the milk, several different tests have been made of the milk of each F_1 cow and on the basis of these tests rest the estimated percentages given in the table. They indicate an average butter-fat content of 4.08%, which is slightly less than the intermediate between 3.4, the butter-fat percentage of pure Holsteins, and 5.0, the butter-fat percentage of pure Guernseys, for the exact intermediate is 4.2%. But the high quantity production of the F_1 cows more than makes up for the slight deficiency in the quality of their milk, so that

TABLE 3

MILK AND BUTTER-FAT PRODUCTION OF PURE-BRED REGISTERED GUERNSEY COWS

COW	FIRST LACTATION PERIOD			SECOND LACTATION PERIOD		
	Age	Time	Total pounds of milk	Age	Time	Total pounds of milk
		months			*months*	
Hailey All Fawn			5,014	4 1/3	11	(5,558)
H. D. Keepsake	2 3/4	9	(3,825)	3 2/3		7,664
H. D. Lady	3	8	(2,897)	3 5/6		4,852
H. H. Dairymaid	2 5/6		6,942	4 1/12		7,093
Hailey Gloria	2 1/3	11 1/2	(5,548)	3 7/12	11 1/2	(6,084)
H. Modena Maid	3	11 1/2	(6,060)	4	8 1/2	(3,983)
Rockbottom Keepsake	2 5/12	9	(4,529)	3 1/2	10 1/2	(4,209)
Rockbottom Leading Lady	2 5/12	7 1/2	(2,121)	3 1/3	10 1/2	(5,307)
Average	2.72	10.0	4,617	3.79		5,593

the average total butter-fat production of each cow is 270.2 pounds, which is 9 pounds more than the average butter-fat production of the pure Holsteins, and 40 pounds more than the estimated butter-fat production of the pure Guernseys. Accordingly on the basis of the records for their first lactation period the F_1 cows seem to surpass either pure breed in butter-fat production and to be better than an intermediate between the pure breeds as regards quantity of milk produced.

A second lactation period has been completed by 13 of the 31 F_1 cows listed in table 1. They of course produce more milk in the second lactation period than in the first, and so comparison should be made with the second lactation period of pure-bred Holsteins and Guernseys, data for which are given in tables 2 and 3. Roberts[1] has shown that the butter-fat percentage of a cow's milk does not change materially with age, so

that we assume it to be for each cow the same in the second lactation period as in the first.

Table 2 shows that 20 pure-bred Holsteins of average age 4.0 years, when the second calf was born, produced an average of 9475 pounds of milk in the second lactation period. Table 3 shows that 8 pure-bred Guernseys of average age 3.8 years when the second calf was born, produced an average of 5593 pounds of milk in the second lactation period. Table 1 shows that the 13 F_1 cows being of average age 3.9 years when the second calf was born, produced an average of 8663 pounds of milk in their second lactation period. This is 812 pounds less than the average production of the pure Holsteins, but is 3070 pounds more than the average production of the pure Guernseys and *exceeds the intermediate between the pure breeds* by 1129 pounds. The deviation is of the same sort as in the first lactation period but is even more striking. As regards quantity production it is clear that the F_1 cows are better than an intermediate between the breeds crossed.

In butter-fat production, using the same percentage estimates as were used for the first lactation period, the Holsteins average 322 pounds, the Guernseys 280 pounds, and the F_1 cows 363 pounds, an excess for the F_1 cows of 41 pounds over the pure Holsteins and of 83 pounds over the pure Guernseys. Again the F_1 cows show superiority over either pure breed in butter-fat production, while in quantity production of milk they are nearer to pure Holsteins than to an intermediate between the pure breeds.

This result is comparable with that observed in the inheritance of size and other quantitative characters both in animals and in plants. In such cases F_1 usually surpasses more or less the intermediate between the races crossed owing to the superior vigor commonly possessed by cross-bred organisms. But F_2 usually varies about a strict intermediate between the races crossed and such we may anticipate will probably be the outcome in this case unless quantity production and quality production to some extent depend on different genetic factors, the point which Mr. Bowlker set out to investigate. If independent genetic factors are really concerned in quantity production and in quality production respectively, their recombination in F_2 may be expected in animals which are both high producers and which give rich milk and such animals should be capable of transmitting this desirable combination of characters to their descendants. Such a result would realize Mr. Bowlker's fondest hopes, and would open great possibilities for the systematic improvement of dairy cattle.

A word should be said as to the theoretically important question whether the reciprocal crosses differ in their results. No consistent difference is observable. Eight of the 31 F_1 cows (indicated by an asterisk in table 1) had Guernsey dams while 23 had Holstein dams. In their first lactation period the cows with Guernsey dams gave less milk but more butter-fat, average 6953 pounds of milk, 287 pounds of butter-fat. But in the second lactation period, three cows with Guernsey dams give a little more than the average amount of milk with exactly the average amount of butter-fat. It seems unlikely, therefore, that any sex-linked factors are concerned in the case.

[1] Roberts, Elmer. Correlation between the percentage of fat in cow's milk and the yield. *J. Agric. Res.*, **14**, No. 2, July 8, 1918.

STUDIES OF MAGNITUDES IN STAR CLUSTERS, X. SPECTRAL TYPE B AND THE LOCAL STELLAR SYSTEM

By Harlow Shapley

Mount Wilson Observatory, Carnegie Institution of Washington

Communicated by G. E. Hale, August 26, 1919

In an earlier communication[1] it has been suggested that the properties of star-streaming and the observed decrease of stellar density with increasing distance from the sun, as well as other observational phenomena, can be explained if the sun is shown to be not far from the center of a large physically-organized star cluster or cloud, which is imbedded in a typical stellar region of the galactic system. Evidence of the existence of such a local group, intermingled with stars of the galactic field, was found from various sources; in particular, the distribution of the brighter stars of spectral type B directly supported the hypothesis that a much flattened local system, of limited extent, surrounds the sun asymetrically, with its equatorial plane inclined some 12 degrees to the plane of the Milky Way.[2] Until recently we have commonly supposed that this stellar assemblage, which is now called the local cluster, constitutes the major part of the known sidereal system; at present we hold it to be a very minor part of the galactic organization.

The completion at the Harvard College Observatory of the first three volumes of the *Henry Draper Catalogue* of stellar spectra permits examination of the distribution of the fainter B-type stars as a graphical test of the existence, dimensions, and inclination of the local system. Miss Cannon has kindly supplied the proof sheets of the third volume of the catalogue in advance of publication. The region covered by